



## Patch Choice Decisions among Ifaluk Fishers

**ABSTRACT** Studies of patch choice decisions among human foragers have failed to explain why foragers do not exclusively exploit the patch with the highest mean profitability. One possible explanation is that profitability rankings are likely to vary daily; however, this instability is not captured when profitabilities are calculated as a sampled average over a longer time span. Here I present data on the patch choice decisions of Ifaluk fishers to evaluate whether men are responding to daily variation in the profitability of their primary fishing patch. Results show that men choose to fish most frequently in the patch with the highest mean profitability. Men fish in alternative patches (alternative from the most profitable patch) when, on that morning or the previous day, return rates in the most profitable patch are lower than the overall mean per capita return rate of alternative patches. Results also indicate that when fishers pursue alternative patches after fishing in the patch with the highest profitability, their mean per capita return rates are generally higher in the alternative patches exploited. However, variance in the profitability of the most profitable patch cannot explain why men exploit two patches, the Nine-mile reef and the dogtoothed tuna patch, which on average have very low profitability. These results and directions for future research are discussed. [Keywords: human behavioral ecology, patch choice decisions, Micronesia]

**O**PTIMAL FORAGING THEORY has provided anthropologists with a set of useful explanatory models aimed at analyzing a range of foraging decisions. These models have generated testable predictions that anthropologists have evaluated against empirical data collected among geographically diverse modern foragers (e.g., Bailey 1990; Hames and Vickers 1982; Hawkes et al. 1982; Hill et al. 1987; Smith 1981, 1983, 1987). Anthropologists, including archaeologists, have most frequently turned to optimal foraging theory to understand why foragers pursue one resource over another (e.g., Bird 1998; O'Connell and Hawkes 1981). The prey choice or diet breadth model specifically models whether a forager should pursue a particular resource or continue to search for other resources. The prey choice model predicts that foragers should only pursue resources that increase their overall mean foraging return rate (Charnov and Orians 1973). The empirical evidence on human foraging decisions has generally been supportive of this prediction (e.g., Hill and Hawkes 1983; Hill et al. 1987).

Under certain conditions the prey choice model may be inappropriate for analyzing decisions concerning which prey to pursue. When prey are distributed nonrandomly in an environment, or foraging strategies constrain the prey species that can be pursued, determining which prey to pursue may be more accurately modeled as the choice between different clumps of resources known as "patches" (Stephens and Krebs 1986). Attempts, however, to employ patch choice models

for understanding human foraging decisions have largely provided mixed results. For example, Smith (1991) found that Inuit hunters spent the most hunter-hours in the most profitable patches each season. However, although the most profitable patches showed no signs of depletion, they were not exploited exclusively. Similarly, O'Connell and Hawkes (1984) found that Alyawara men chose to hunt in the most profitable patch with the greatest frequency, but they did not hunt in the most profitable patch exclusively. Beckerman (1983) reported that Bari men also did not exclusively exploit the most profitable patch during five sample time periods.

One reason that foragers may not exclusively exploit the patch with the highest mean profitability is because of daily variation in environmental conditions, such as prey movements or weather conditions (Kaplan and Hill 1992). If daily fluctuations in environmental conditions do not equally impact the profitability of patches across a habitat, the most profitable patch on average may not be the most profitable patch every day. Thus, daily variation in patch profitability may warrant that the most profitable patch on average is not exploited exclusively. Previous work (see Kaplan and Hill 1992; Kelly 1995 for reviews) has been unable to empirically evaluate the claim that foragers are responding to short-term variation in patch profitabilities.

This article explores the patch choice decisions of Ifaluk fishers. The data presented here provide an opportunity to evaluate patch choice decisions in response to daily fluctuations

in patch profitability. I will evaluate shifts in the patches exploited by Ifaluk fishers as a response to daily fluctuations in the gains achieved in their primary fishing patch. Hypotheses will be evaluated against empirical data on the fishing activities of Ifaluk men.

### PATCH CHOICE MODELS

Foraging models developed by behavioral ecologists, including patch choice models,<sup>1</sup> assume that organisms will choose food items and foraging activities that maximize some fitness-related currency. In empirical tests of foraging models, the currency most frequently employed by human and non-human behavioral ecologists is net calories per unit time. The expectation that gain rate maximization is the goal of any organism's foraging decision is based on the assumption that natural selection will produce decision-making algorithms that result in optimal decisions with respect to the alternative choices available and the tradeoffs the organism faces. All organisms face tradeoffs concerning how to allocate their time. Because foraging often exposes organisms to predation risks, and time spent foraging is time that cannot be used for other fitness enhancing behaviors, selection is expected to have favored design features in organisms that enable them to maximize the rate at which they can accrue resources.

The earliest patch choice model, developed by MacArthur and Pianka (1966), analyzes a forager's choice between exploiting nondepleting patches, which are known as habitats (Stephens and Krebs 1986:35). The main result of the model is that a forager should exploit the patch with the highest profitability, measured as net energy gain per unit of time. However, this model was not widely applicable since most patches do experience some form of depletion as a result of foraging activities, environmental conditions (e.g., seasons), or prey behavior. The marginal value theorem (MVT) (Charnov 1976; Charnov and Orians 1973) specifically addressed this shortcoming of the MacArthur-Pianka patch choice model. As Smith (1991:250-252) points out, however, the MVT does not answer the same question as the MacArthur-Pianka model. The MVT answers this question: How long should a forager remain in a particular patch that it has already chosen? Thus, instead of analyzing which patch a forager should exploit, the MVT evaluates how long to remain in a patch in relation to other known exploitable patches.

The critical component of the MVT is the relationship between the amount of time an organism spends in a patch and the net energy it acquires in the patch, known as the *gain function*. The shape of the gain function within a patch determines when a forager should leave a patch and exploit another patch. The MVT assumes that patches will exhibit a negatively accelerating gain function (Charnov 1976; Charnov et al. 1976). The rate at which resources within a patch can be harvested declines as a function of time spent there. In other words, a forager's marginal gains diminish as his foraging time within the patch increases. The MVT predicts that

a forager should continue to forage in a patch as long as the returns he expects from the next unit of foraging time in the patch are greater than the returns he expects from searching for and foraging in another patch.

Unfortunately, no study of human foraging decisions, this one included, has accurately measured the gain functions of exploitable patches (Kaplan and Hill 1992:180; Smith 1991:256-258). The main difficulty in acquiring these data is that it would be necessary to experimentally manipulate foraging behavior. Naturalistic observations of foraging behavior will not provide an accurate measure of within patch gain functions if foragers respond to fluctuations in resource availability. On days in which foragers expect low foraging returns in a certain patch they are likely to avoid that patch, and, thus, naturalistic observations of foraging behavior within a patch will be biased toward "good foraging days." One strategy to avoid this bias is to request that foragers pursue resources in areas that they would not normally choose to forage, or request that they forage on days that they wouldn't normally forage (e.g., Hawkes et al. 1991).

Owing to the challenges of accurately measuring the gain function within a patch, as well as measuring fluctuations in the marginal productivity of the entire habitat (Smith 1991:258), most anthropological studies have simply compared the average return rates of patches in an environment to examine whether foragers are making patch choice decisions that maximize their overall mean foraging return rate (e.g., Beckerman 1983; Hames 1980). However, the MVT does not predict that foragers should necessarily exploit the patch with the highest average return rate when patches are encountered simultaneously, since "choosing the patch with the highest average profitability will not necessarily maximize the overall foraging return rate" (Kaplan and Hill 1992:180; see also Hill et al. 1987). The MVT predicts that when the marginal returns from foraging in a patch fall below the average rate of return from the entire set of patches exploited, including the costs of traveling to the other patch, a forager should switch patches. Foragers should deplete all patches until the marginal gains in each patch are equal and total available or optimal foraging time has been expended.

In addition to a lack of information on within patch gain functions, tests of human patch choice decisions have been further impeded by complications in assessing the optimal time that foragers should allocate to resource acquisition. In other words, without data on the opportunity costs individuals face while foraging (e.g., the forgone benefits of parenting, mating, etc.), it is impossible to determine the constraints that foragers confront when determining the amount of time they will devote to resource acquisition on a given day. Although this information is critical when deriving predictions about patch choice decisions,<sup>2</sup> there are no patch choice studies that have collected these data and used them to model optimal foraging time. This study is no exception. With knowledge of these shortcomings, I proceed cautiously and recognize that although the data presented here provide valuable insights into Ifaluk foraging decisions and offer an opportunity to evaluate several hypotheses that have

not been previously tested in the foraging literature, these data fall far short of the sophisticated data that would be needed to properly test hypotheses derived from patch choice models.

**ETHNOGRAPHIC BACKGROUND**

Ifaluk is a coral atoll located in Yap State, which is part of the Caroline Islands of the Federated States of Micronesia, at 7° 15' north latitude and 147° east longitude. The nearest inhabited atoll is Woleai, 53 km west of Ifaluk, and Yap, the largest island in Yap State, is located about 560 km northwest of Ifaluk. Ifaluk is part of the Woleai region of Yap State, which also includes the islands of Elato, Euripik, Faraulep, Lamotrek, and Woleai. Ifaluk consists of four atolls, two of

which are inhabited (see Figure 1). The total landmass of the four atolls is 1.48 sq. km and the nearly circular lagoon is 2.43 sq. km (Freeman 1951:237-238, 273-274). A 35-meter channel that is less than a meter deep during high tide and completely dry during low tide separates the two inhabited atolls, Falalop and Falachig. The channel can easily be crossed on foot even during high tide. It is estimated that Ifaluk receives between 254 and 305 centimeters of rain per year (Tracey et al. 1961). Daily temperatures range from 21-35°C and remain nearly constant throughout the year. The two seasons on Ifaluk are differentiated by the presence of northeast trade winds from October through May.

There are four villages on Ifaluk, two on each inhabited atoll. Villages consist of 5-13 matrilineal compounds. The 36

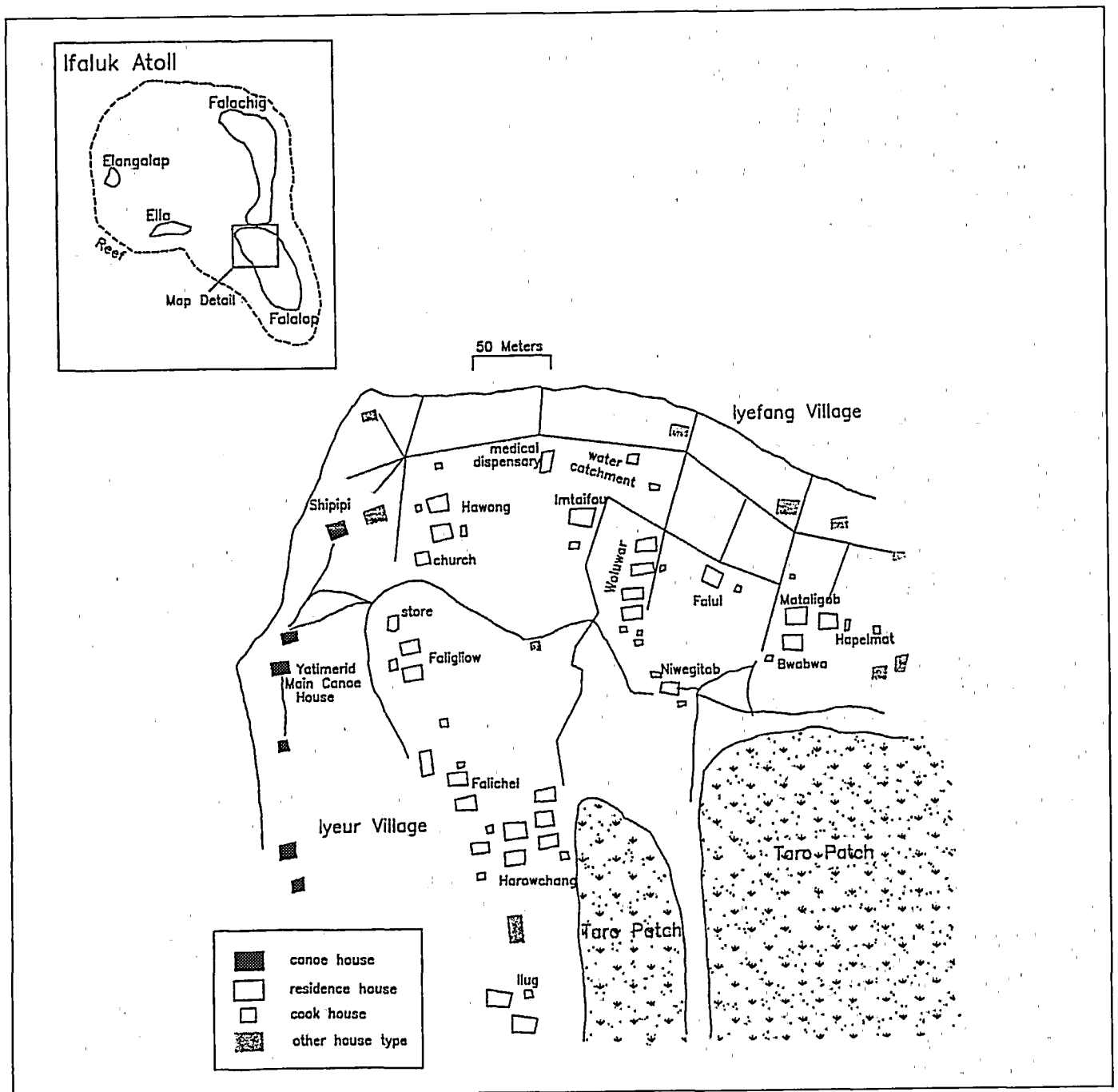


FIGURE 1. Map of Ifaluk Atoll showing Iyeur and Iyefang villages.

TABLE 1. Fishing method, prey type, location, and time of exploitation of each fishing patch.

Patch Type	Fishing Method	Prey	Location	Time of Day Exploited
Yellowfin tuna	trolling (morning trolling)	yellowfin tuna	mid-high sea beyond reef	early morning
Nine-mile reef	trolling (nine-mile reef fishing)	yellowfin tuna, reef fish	mid-high sea, nine-mile reef	evening through early afternoon
Dogtoothed tuna	torch fishing	dogtoothed tuna	deep sea beyond reef	dusk through evening
Lagoon-bottom	rope fishing	reef fish	lagoon bottom	late morning through mid-afternoon
Reef fish	line, spear, and trap fishing (solitary fishing)	reef fish	lagoon	morning, afternoon, evening

total compounds on Ifaluk range in size from one to four houses and 3–35 residents. Houses are composed of either nuclear or extended families, and often include several adopted children. There are seven ranked clans on Ifaluk; the five highest-ranking clans are chiefly clans. Clans are not localized and all four villages have residents from each clan. The observational data presented in this article were collected on Falalop atoll from December 1994 to April 1995. Of the 189 individuals who lived on Falalop during the 1994–95 field session, 99 resided in Iyeur village and 90 resided in Iyefang village. The total population on Ifaluk during the field session was over 600 individuals.

### Subsistence

Ifaluk primarily maintains a subsistence economy. The diet largely consists of pelagic and reef fish, taro, breadfruit, and coconut. Pigs, chickens, and dogs are also raised for consumption and usually only prepared for bimonthly feasts. A store is maintained on each of the inhabited atolls that offers flour, rice, and other assorted goods.<sup>3</sup> White rice is the most frequently purchased food product, although not all residents can afford it (most residents do not have an income).<sup>4</sup> There is no refrigeration on Ifaluk. Fish are occasionally smoked, but competition with the dogs, cats, and rats makes long-term storage difficult. For a more detailed description of subsistence on Ifaluk, see Sosis (1997).

Fishing is the primary means of protein acquisition on Ifaluk and is exclusively pursued by males. Fishing activities differ significantly by season. Here I will focus on fishing patches observed during the trade wind season (October–May).

Patches are typically defined according to location and species. However, the technology and foraging strategies used among human populations presents an additional dimension that must be considered (Smith 1991). If the foraging technology operates indiscriminately across a range of species (e.g., fishing nets), different prey in the same location may constitute one patch. On the other hand, if the technology or strategies used to pursue certain species are mutually exclusive, prey in a similar location may constitute more than one patch. On Ifaluk, no fishing methods could be used simultaneously. Therefore, here I have defined fishing patches according to location, prey species, and fishing method. There are five fishing patches exploited during the trade wind season, four of which are exploited by unique fishing methods. Below, I describe each patch and the fishing

method used to exploit the patch (see Table 1 for summary of patch descriptions).

### Yellowfin Tuna Patch (Morning Trolling)

Most mornings before dawn during the trade wind season, males congregate at the central canoe hut on Falalop to prepare for morning trolling.<sup>5</sup> Men spend about a half-hour preparing their fishing lines and loading the mast and fishing equipment onto the canoe.<sup>6</sup> After the canoes are prepared, all the men who are present help to push each canoe that will be sailing that morning into the lagoon. On average canoes depart at 4:56 a.m. (median = 5:01 a.m., range 3:24 a.m.–5:58 a.m.,  $n = 183$ ). Fishers paddle through the lagoon toward a break in the reef, where they raise their sail and enter the open waters. Once they are beyond the reef, fishers watch the foraging behavior of birds to determine where schools of fish are located. Men troll primarily for yellowfin tuna, which accounted for 89 percent of the harvest by weight during the observation period ( $n = 114$  days). On average, canoes return at 7:53 a.m. (median = 7:37 a.m., range 6:50 a.m.–11:43 a.m.,  $n = 183$ ). Upon their arrival, men throw their catch into a pile that is distributed by a divider after all the canoes have returned (see Sosis 2000a).

There are four large sailing canoes on Falalop, the atoll where this study was conducted. During roughly 70 percent of the observations, four or five adult males sailed on a canoe (range 2–7;  $n = 183$ ). Each canoe is owned and maintained by a specific matriline, and hence compound. Each compound is historically associated with a particular canoe and males are expected to fish on the canoe that is associated with the compound in which they were raised, their *natal compound*. Indeed, 86.4 percent ( $n = 815$ ) of the observed time that males fished they sailed on the canoe that was associated with their natal compound. Although residence patterns are matrilineal, married men fished on the canoe associated with their wife's compound only 5.6 percent ( $n = 177$ ) of the times they fished. Despite the consistency with which men adhere to cultural expectations, these rules appear flexible, especially when there are not enough men to sail a particular canoe.

### Nine-Mile Reef Patch (Nine-Mile Reef Fishing)

Men occasionally fish at a reef located nine miles west of Ifaluk appropriately known as Nine-mile reef.<sup>7</sup> Men travel on the large sailing canoes and thus require strong winds to

reach the reef. Preparations for the journey are similar to preparations for morning trolling. Once at Nine-mile reef, men troll for yellowfin tuna, although if the conditions on arrival are not appropriate for trolling they also pursue reef fish. To reach Nine-mile reef before dawn, men depart on their 5–7-hour voyage at about 10:00 in the evening and return around mid-afternoon the following day. The two events observed during the sample period occurred from 10:30 p.m.–2:19 p.m. and 10:02 p.m.–5:32 p.m. The long journey is made even more difficult by certain taboos, such as the prohibition on eating and drinking during the entire fishing trip. While the men are fishing, women prepare bowls of breadfruit and taro for an atoll-wide feast, which occurs when the men return.

### **Dogtoothed Tuna Patch (Torch Fishing)**

In addition to morning trolling and Nine-mile reef fishing, men also use large sailing canoes to torch fish for dogtoothed tuna. Torch fishing occurs in two stages. First, torch fishers catch flying fish in small hand nets roughly two feet in diameter. Men use torches made from dried coconut fronds to attract the flying fish to the sailing canoe. In the second stage, the flying fish are used as bait for deepwater trolling to catch large dogtoothed tuna (80 percent by weight of all fish caught torch fishing were dogtoothed tuna [ $n = 114$  observation days]).

Torch fishing is the most ritualized fishing method on Ifaluk. Men who torch fish are subject to a number of taboos, especially food taboos that determine what, when, and where they may eat. Men must prepare for several weeks before they can torch fish. Preparations primarily consist of collecting and drying coconut fronds that they will wrap tightly together and use as torches. On days that men plan to torch fish, most of the day is spent making torches and fishing nets in the canoe house (see Sosis 2000b). Around the time of each new moon, the magician determines whether the cycle of the moon is good for torch fishing.<sup>8</sup> If it is deemed propitious, those canoes that are prepared may fish. When the sun sets the men depart on their sailing canoes in an orderly fashion (mean = 7:02 p.m., median = 6:58 p.m., range 6:05 p.m.–9:05 p.m.,  $n = 17$ ). A fire is set on the beach and in a single file line the men carry the torches out to the large sailing canoe. Women and children often spend the early part of the evening on the shore watching the canoes. The light of the flame against the large white sail in the open sea is a spectacular sight. The canoes return when the moon rises (mean = 12:04 a.m., median = 12:30 a.m., range 9:10 p.m.–2:06 a.m.,  $n = 17$ ), thus as the month progresses men are able to fish for longer and longer each evening until a new moon appears.

### **Reef Fish Patch (Solitary Fishing)**

The reef fish patch is exploited by several solitary fishing methods. During the observation period, solitary fishing resulted in the capture of 62 different species of reef fish. The main type of solitary fishing during the trade wind season is

line fishing with either octopus or land crabs used as bait. Almost all males over 15 years old own the solitary outrigger canoes used for line fishing. Spear and trap fishing were also observed during the trade wind season (see Burrows and Spiro 1957 for a description). None of the solitary fishing methods consist of randomly searching the entire lagoon for fish. Men know where certain species of reef fish are located and they prepare the appropriate bait, hooks, traps, or nets before fishing in each location. Men begin solitary fishing in the morning or early afternoon (mean = 12:31 p.m., median = 12:49 p.m., range 8:59 a.m.–3:10 p.m.,  $n = 54$ ) and typically return throughout the late morning and afternoon (mean = 2:50 p.m., median = 3:17 p.m., range 10:43 a.m.–5:48 p.m.,  $n = 54$ ).

### **Lagoon-Bottom Patch (Rope Fishing)**

Rope fishing also occurs in Ifaluk's lagoon and specifically targets species that live in certain areas on the lagoon floor. Rope fishing is an atoll-wide event; that is, all men who reside on the atoll are expected to participate. Preparations take roughly two hours and commence after the men complete their morning rounds of cutting palm sap. Rope fishing utilizes two ropes that are each over 50 meters long. Preparations mainly consist of collecting coconut fronds that are tied to these long ropes. The elders of the community lead the fishing party in two or three mid-sized paddling canoes. On 20–25 solitary outrigger canoes, the rest of the men travel to the fishing site where the elders will organize all of the canoes into a circle. The two ropes are tied together and passed along to each of the canoes. A fishing net is secured in the center of the circle. Most of the men proceed into the water, while a few remain above to watch the canoes. Wearing diving masks, men place the rope on the lagoon floor and swimming slowly and in synchrony, move the rope toward the fishing net. The coconut frond covered rope is intended to frighten and hence drive the fish toward the net. When the circle created by the men becomes small, the men scream and splash making a great commotion to chase the fish into the net. The nets are then emptied into the canoes of the elders. This process is repeated four to five times at different locations in the lagoon. The fish are then placed in a communal pile and divided amongst the residents of the atoll. The two observed rope-fishing events occurred from 11:00 a.m.–1:45 p.m. and 10:40 a.m.–3:01 p.m.

### **METHODS**

The data presented in this article were collected over 75 continuous days from December 19, 1994, to March 3, 1995. These data are part of a larger sample of Ifaluk fishing data that have been reported on elsewhere (Sosis 2000a; Sosis et al. 1998). It was decided to concentrate on this 75-day subset of the data because it is the largest block of continuous data on fishing activities that was collected during the 1994–95 field session. During the field session I resided on Falalop atoll and collected observational data on fishing activities in Falalop's two villages of Iyeur and Iyefang.

In order to collect data on trolling for yellowfin tuna, every morning during the observation period I observed and recorded (1) which of the canoes set sail, (2) the names of the fishermen on each canoe, (3) the time of departure and return for each canoe, and (4) the weight and species of each fish caught by canoe. Data on torch, rope, and Nine-mile reef fishing were collected opportunistically. These fishing events were easily monitored because they were public events and widely discussed before occurring. Data collection during these events was identical to the methods just described. *The dataset on these fishing activities during the observation period is complete; no fishing events were missed and no data were missed during any event.*

Solitary fishing activities occurred in the lagoon and were thus easily monitored because of the high visibility of the activity.<sup>9</sup> Observation days were spent at one or several of the Falalop canoe houses that line the shore of the lagoon. All solitary fishing activities commenced from one of these canoe houses. Data collection activities that required me to leave the shoreline (e.g., spot observations), never caused me to lose sight of the lagoon for more than a half-hour. Of 39 total solitary fishing events during the observation period, data were missed (specifically, time of departure) during only three events. For each solitary fishing event I recorded (1) the name of the solitary fisherman, (2) the time of departure and return, and (3) the weight and species of all fish caught.

To summarize, the data set is a nearly complete record of all fishing activities for all Falalop men over 75 days during the trade wind season. All statistical analyses were conducted using SAS.

## HYPOTHESES AND RESULTS

### Assumptions

All models of behavior, whether employed by behavioral ecologists or others, are based on assumptions about the decision makers and their environment. The predictions presented below share the following assumptions.

1. All patches have negatively accelerating daily gain curves. This may be because of prey depletion, changing environmental conditions (e.g., calming winds or rising moon), or daily fluctuations in prey species' behavior.
2. Decisions concerning which patch to exploit and which fishing method to use are interdependent. Choosing to exploit a certain patch implies that a specific fishing method will be used. All fishing methods are mutually exclusive; the same men cannot concurrently engage in more than one fishing method at a time.
3. The energy expended engaging in each fishing method is similar. In previous work it was estimated that the mean caloric expenditure of trolling for yellowfin tuna and solitary fishing were on average 4.7 and 4.9 kcal/min respectively.<sup>10</sup> The rate of energy expenditure for exploiting Nine-mile reef is likely to be very similar to the yellowfin tuna patch because the main difference is simply travel time to the patch. Owing

to the video recording techniques used to estimate energy expenditure during this study (see Sosis 1997), it was not possible to collect energy expenditure data on torch fishing (which occurred at night) and rope fishing (which occurred under water). Here I will assume that the energy expended in acquisition is equal for all fishing methods and therefore these costs will be ignored in calculations of net energy gain.

4. Handling and processing time is similar for all species of fish caught. No species of fish requires any more processing or cooking time than others. Women partake in processing and cooking for at least some events following each fishing method.
5. All fish caught have similar caloric values. Indeed, the caloric value of yellowfin tuna is 1,080 kcal and the average caloric value of five species of reef fish is 1,074 kcal (Genesis R&D Nutrition and Labeling Software).<sup>11</sup>

### Predictions 1 and 2

Extending the MVT, Smith (1991:257–258) argues that within patch profitability (net energy gain per unit of time) should be positively correlated with patch residence time. Smith cautions that this prediction is not a direct test of the MVT, but under specified assumptions it is a “valid correlate.” These assumptions are that patches experience a negatively accelerating gain curve, these gain curves do not overlap one another, and that each patch can potentially be exploited on any given day. As mentioned above, all patch choice studies among human foragers have assumed (either implicitly or explicitly) the gain functions within patches. Here I will do the same. However, it is reasonable to assume that each fishing patch on Ifaluk experiences *daily* resource depression. This may not only be a result of foraging induced prey depletion, but also a result of changing wind conditions and a reduction in feeding activity of the prey species. The second assumption may be more problematic, but it is currently impossible to evaluate whether this assumption is valid for Ifaluk fishing patches. In regard to the third assumption, potential patch exploitation on Ifaluk varies by weather conditions, thus not all patches can be exploited on a given day. Trolling (used to exploit the yellowfin tuna, dogtoothed tuna, and Nine-mile reef patch) requires strong winds and tides whereas solitary fishing requires calm winds and tides. Rope fishing can occur under either of these conditions. Therefore, on windy days Ifaluk men can exploit the yellowfin tuna, dogtoothed tuna, Nine-mile reef, and lagoon-bottom patch, and on days of calm winds men can exploit the lagoon-bottom and reef fish patch.

**Prediction 1:** The mean per capita return rates of exploiting the yellowfin tuna, dogtoothed tuna, Nine-mile reef, and lagoon-bottom patch will be positively correlated with the total fisher hours spent exploiting each patch.

**Prediction 2:** The mean per capita return rates of exploiting the lagoon-bottom and reef fish patch will be positively

TABLE 2. Observed frequency of patch exploitation and within patch mean per capita return rates during 75-day observation period.

Patch Type (Fishing Method)	Total Amount Caught (kg)	Percentage of Total Amount Caught	Total Travel and Residence Time (hr)	Per Capita Return Rate (kg/hr)	Day-Event Frequency
Yellowfin tuna (morning trolling)	3515.4	86.7	2090.6	1.68	58
Reef fish (solitary fishing)	94.6	2.3	95.6	0.99	18
Lagoon-bottom (rope fishing)*	104/69.4	2.6/1.7	126.2/88.0	0.82/0.79	1/1
Dogtoothed tuna (torch fishing)	250.3	6.2	584.9	0.43	12
Nine-mile reef (nine-mile reef fishing)	22.4	0.6	196.1	0.11	2
Total	4056.1	100.0	3181.3		

\* Windy day/nonwindy day.

correlated with the total fisher hours spent exploiting each patch.

### Results: Predictions 1 and 2

The frequency that each patch type was exploited is presented in Table 2. If men were exploiting a patch, there was never another group of men simultaneously exploiting a different patch. Men fished in the yellowfin tuna patch on 77 percent (58 out of 75) of the observations days, which is slightly more than the percentage of days men fished in the yellowfin tuna patch in the larger data set, at 72 percent (82 out of 114 days). The total amount caught, total travel and patch residence time, and mean per capita return rates are presented for each patch type in Table 2. Trolling for yellowfin tuna has the highest mean per capita return rate and the most fisher hours, which is consistent with Prediction 1. Contrary to our expectation, the rank order of the mean per capita return rates and total fisher hours spent in the dogtoothed tuna, lagoon-bottom, and Nine-mile reef patch indicates that on windy days men spend more time in the dogtoothed tuna and Nine-mile reef patches than in the lagoon-bottom patch, which has a higher profitability.

Solitary fishing has a higher mean per capita return rate than rope fishing on nonwindy days, and thus we expect men to spend more hours solitary fishing than rope fishing. Consistent with Prediction 2, men spent slightly more time solitary fishing than rope fishing.

### Predictions 3, 4, 5, and 6

Ifaluk men face a series of patch choice decisions throughout the day. Yellowfin tuna is the first patch that can be exploited each day and thus it is logical to consider the choice of whether or not to exploit this patch as a baseline decision and evaluate how responses to this decision influence subsequent patch choice decisions. Yellowfin tuna was the most frequently exploited fishing patch over the observation period. Indeed, men exploited the yellowfin tuna patch on more days than all other fishing patches combined. Given that the yellowfin tuna patch is the most profitable patch (see Table 2), why would foragers ever choose to exploit another patch? Although men may fish most frequently in the most profitable patch, patch profitabilities are likely to vary each day. Men are expected to respond to this variation in patch productivity and it is assumed that on any given day

men will fish in the most profitable patch *on that day*.<sup>12</sup> Thus, alternative patches (lagoon-bottom, dogtoothed tuna, nine-mile reef, reef fish) are likely to be pursued when fishers perceive low profitabilities in the yellowfin tuna patch and thus avoid the yellowfin tuna patch on that day, or fishers exploit the yellowfin tuna patch but discover while trolling that it has low profitability on that day.

To assess the profitability of the yellowfin tuna patch, Ifaluk men use environmental cues such as wind patterns, tide strength, and the amount of fish that were caught on the previous day. Indeed, previous results indicate that, controlling for participation on the previous day, the total amount caught trolling for yellowfin tuna on the previous day is a significant positive predictor of whether a man will exploit the yellowfin tuna patch on a given day (Sosis 2000a). In other words, if the yellowfin tuna catch on the previous day was large, it is probably a reliable indication that returns from morning trolling will be favorable today, and thus men choose to exploit the yellowfin tuna patch. However, if returns on the previous day were poor, or other environmental cues indicate that the profitability of the yellowfin tuna patch is likely to be low, men may choose to invest their energy in the exploitation of alternative patches.

Assuming that profitabilities are at least partially independent across patches (i.e., a poor day for trolling for yellowfin tuna does not necessarily mean low returns in other patches), we expect men to exploit alternative patches when the return rate from trolling for yellowfin tuna is expected to be low. But how low must the return rate be? In other words, at what point on the yellowfin tuna patch gain curve (i.e., at what level of marginal gains) should Ifaluk fishers exploit an alternative patch? The MVT predicts that all patches will be depleted until they reach the same profitability. When the marginal gains within a patch fall below the foraging return rate of alternative patches, the forager should travel to another patch. Thus, when the daily mean per capita return rate from trolling for yellowfin tuna falls below the overall mean per capita return rate of exploiting alternative patches, men should exploit those patches.

**Prediction 3:** Men will not exploit the yellowfin tuna patch on mornings following a day when the mean per capita return rate within the yellowfin tuna patch was below the mean per capita return rate of alternative patches.

**Prediction 4:** On days that returns in the yellowfin tuna patch are expected to be low and therefore no men troll for

TABLE 3. Daily mean per capita return rates (kg/hr) by fishing patch over 75 observation days.

Date	Yellowfin Tuna Per Capita	Reef Fish Return Rate	Nine-Mile Reef	Date	Yellowfin Tuna	Reef Fish Per Capita	Nine-Mile Reef Return Rate	Lagoon-Bottom	Dogtoothed Tuna
12/19/94	0.921			1/26/95	2.316				
12/20/94				1/27/95	0.000	0.736			
12/21/94	2.633			1/28/95		1.049			
12/22/94	0.499			1/29/95	0.000	1.047			
12/23/94	0.181			1/30/95	1.963				
12/24/94				1/31/95	0.247				
12/25/94				2/1/95		1.039			
12/26/94	3.547			2/2/95					
12/27/94	4.123			2/3/95	0.366	1.060			
12/28/94	1.654			2/4/95				0.789	
12/29/94	1.427			2/5/95		1.086			
12/30/94				2/6/95	0.451			0.824	
12/31/94	1.359			2/7/95			0.000		
1/1/95	2.259			2/8/95		0.904			
1/2/95	1.909			2/9/95	4.149				
1/3/95	0.247			2/10/95	2.866				
1/4/95	1.336			2/11/95	0.415				
1/5/95	1.163			2/12/95		0.806			
1/6/95				2/13/95	0.648	1.591			
1/7/95	0.560			2/14/95	3.809				
1/8/95	2.138			2/15/95	0.000	1.740			
1/9/95	0.514			2/16/95	5.952				
1/10/95	1.313			2/17/95	0.000				
1/11/95			0.283	2/18/95	0.992				0.005
1/12/95	1.696			2/19/95	0.521	0.852			0.053
1/13/95	0.874			2/20/95	1.992				
1/14/95	1.658	0.710		2/21/95	0.785	0.979			0.193
1/15/95	1.247			2/22/95	0.000	2.000			0.479
1/16/95	0.773	1.108		2/23/95	4.290				0.570
1/17/95		0.274		2/24/95	0.000				2.196
1/18/95	4.447			2/25/95	0.000	0.762			0.539
1/19/95	9.035			2/26/95					0.047
1/20/95	4.119			2/27/95					1.072
1/21/95	0.833			2/28/95	0.085				0.011
1/22/95	4.356			3/1/95	0.256				0.486
1/23/95	0.236			3/2/95	0.000				0.183
1/24/95	1.190			3/3/95	1.352				
1/25/95	0.335								

yellowfin tuna in the morning, men will exploit alternative patches.

**Prediction 5:** Men will exploit alternative patches on days when the yellowfin tuna patch return rate on that morning is lower than the mean per capita return rate for alternative patches.

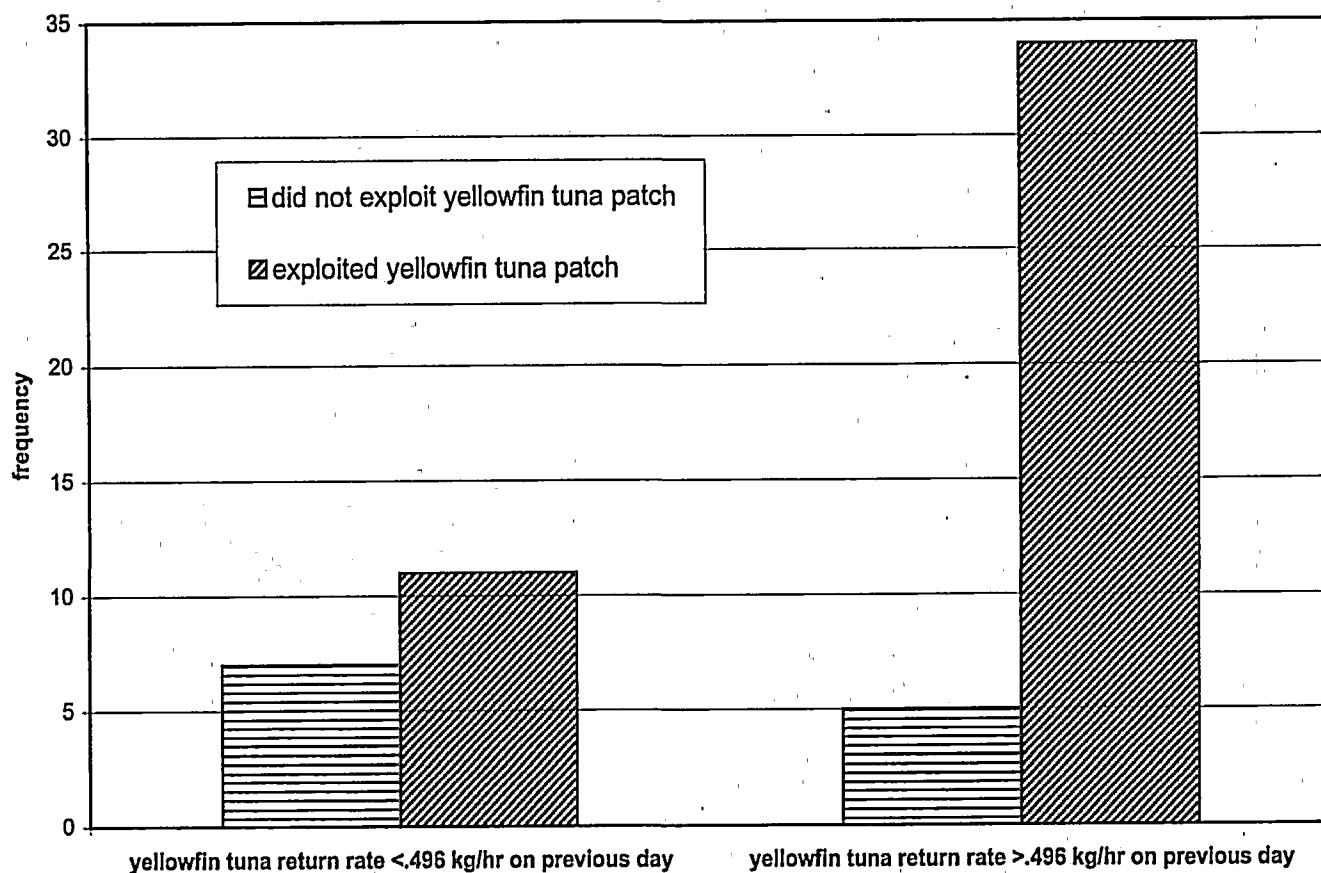
**Prediction 6:** On mornings when men troll for yellowfin tuna, the mean per capita return rate for any alternative patches exploited will be higher than the mean per capita return rate from trolling for yellowfin tuna on that day.

### Results: Prediction 3

Table 3 presents the per capita return rates by day for each patch. The mean overall foraging return rate (total amount caught/total fisher hours) for the four alternative fishing patches is 0.496 kg/hr, which will be referred to as the threshold value. On 18 days the return rate from trolling for yellowfin tuna was below the threshold value. Men avoided the yellowfin tuna patch on 7 of 18 days (39 percent) when the return rate was below the threshold value on the previous day. Men avoided the yellowfin tuna patch on 5 of 39

(13 percent) days when the return rate from trolling on the previous day was greater than the threshold value (see Figure 2). On the five days that men did not troll for yellowfin tuna, the return rates on the previous day were all less than 1.43 kg/hr. Thus, men never avoided the yellowfin tuna patch when the return rate on the previous day was above average (i.e., > 1.68 kg/hr; see Table 2). Stated another way, of 17 days that men did not troll for yellowfin tuna, five days were preceded by days in which the mean per capita return rate of trolling for yellowfin tuna was greater than the threshold value (but less than the overall mean per capita return rate for the yellowfin tuna patch), seven days were preceded by days in which the mean per capita return rate of trolling for yellowfin tuna was less than the threshold value, and five days were preceded by days in which men did not troll at all on the previous day. The five times that men did not troll on consecutive days were all preceded by days in which the mean per capita return rate from trolling was less than the threshold value. Thus, on 12 of 17 days in which men did not troll for yellowfin tuna, the previous trolling event had resulted in returns less than the threshold value. Results of a chi-square analysis suggest that men were less likely to troll





**FIGURE 2.** The frequency that the yellowfin tuna patch was exploited when the yellowfin tuna patch productivity on the previous day was greater than or less than 0.496 kg/hr (threshold value).

for yellowfin tuna on mornings following a day when the mean per capita return rate for trolling was less than the threshold value ( $X^2 = 5.04$ ;  $p = .025$ ;  $n = 57$ ;  $df = 1$ ). These results are strengthened if the five days that men did not troll on consecutive days are included in the analysis ( $X^2 = 11.26$ ;  $p < .001$ ;  $n = 62$ ;  $df = 1$ ).

#### **Results: Prediction 4**

As shown above, men avoid the yellowfin tuna patch when returns are expected to be low (as indicated by low per capita return rates on the previous day). On days that men did not troll for yellowfin tuna, men were twice as likely to pursue alternative fishing patches (see Figure 3). Men exploited alternative fishing patches on 11 of 17 days (65 percent) that men did not troll for yellowfin tuna. Of the 58 days men trolled for yellowfin tuna, men exploited alternative patches on only 19 of those days (33 percent). Results of a chi-square analysis indicate that men are more likely to pursue an alternative patch when there was no trolling for yellowfin tuna in the morning ( $X^2 = 5.6$ ;  $p = .018$ ;  $n = 75$ ;  $df = 1$ ).

#### **Results: Prediction 5**

On 18 days, the mean per capita return rate for trolling for yellowfin tuna was less than the threshold value; on 10 of these days men pursued alternative fishing patches (56 percent). Men pursued alternative fishing patches on only 8 of

the 40 days (20 percent) that the mean per capita return rate in the yellowfin tuna patch was greater than the threshold value (see Figure 4). Results of a chi-square analysis indicate that men are more likely to pursue an alternative patch on days when the mean per capita return rate for trolling is less than the threshold value ( $X^2 = 7.33$ ;  $p = .007$ ;  $n = 58$ ;  $df = 1$ ).

#### **Results: Prediction 6**

Men exploited alternative patches on 30 of 75 observation days and on 19 of these days, men had trolled for yellowfin tuna in the morning. On four of these 19 days, men exploited two alternative patches. Data in Table 3 indicate that of 23 exploited alternative patches on days that men trolled for yellowfin tuna, 16 (70 percent) resulted in higher mean per capita return rates than trolling on that day. The results vary widely by method. The only rope-fishing event to occur on a day that men trolled for yellowfin tuna showed an improvement over the mean per capita return rate of trolling for that day. Ten of 12 solitary fishing events and 5 of 10 torch-fishing events resulted in a higher return rate than the trolling event that occurred on the same day. The Nine-mile reef and yellowfin tuna patch were never exploited on the same day.

## **DISCUSSION**

The results presented above show that Ifaluk fishers primarily pursue alternative lower ranked patches when the returns

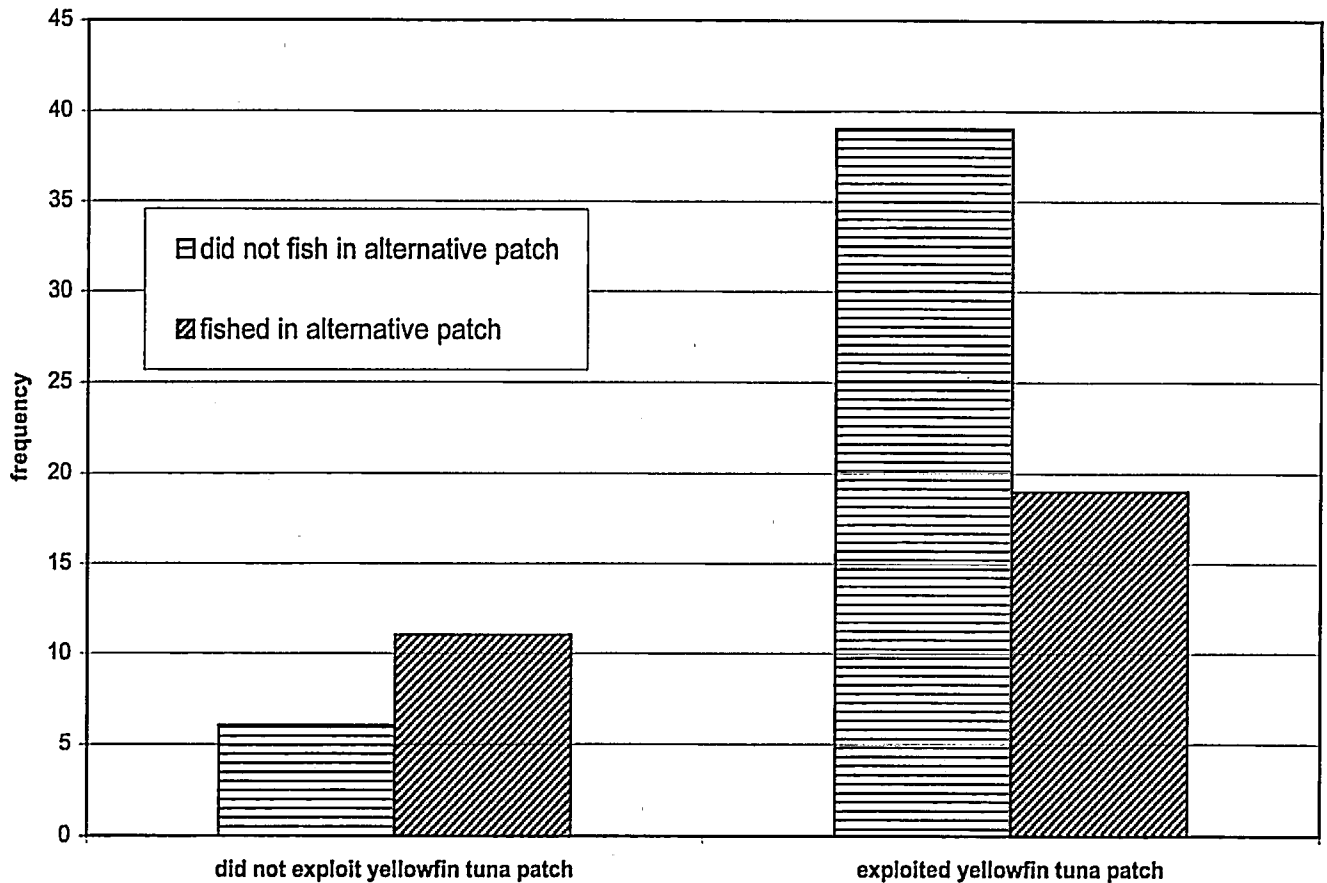


FIGURE 3. The frequency that alternative patches were exploited when men did and did not exploit the yellowfin tuna patch in the morning.

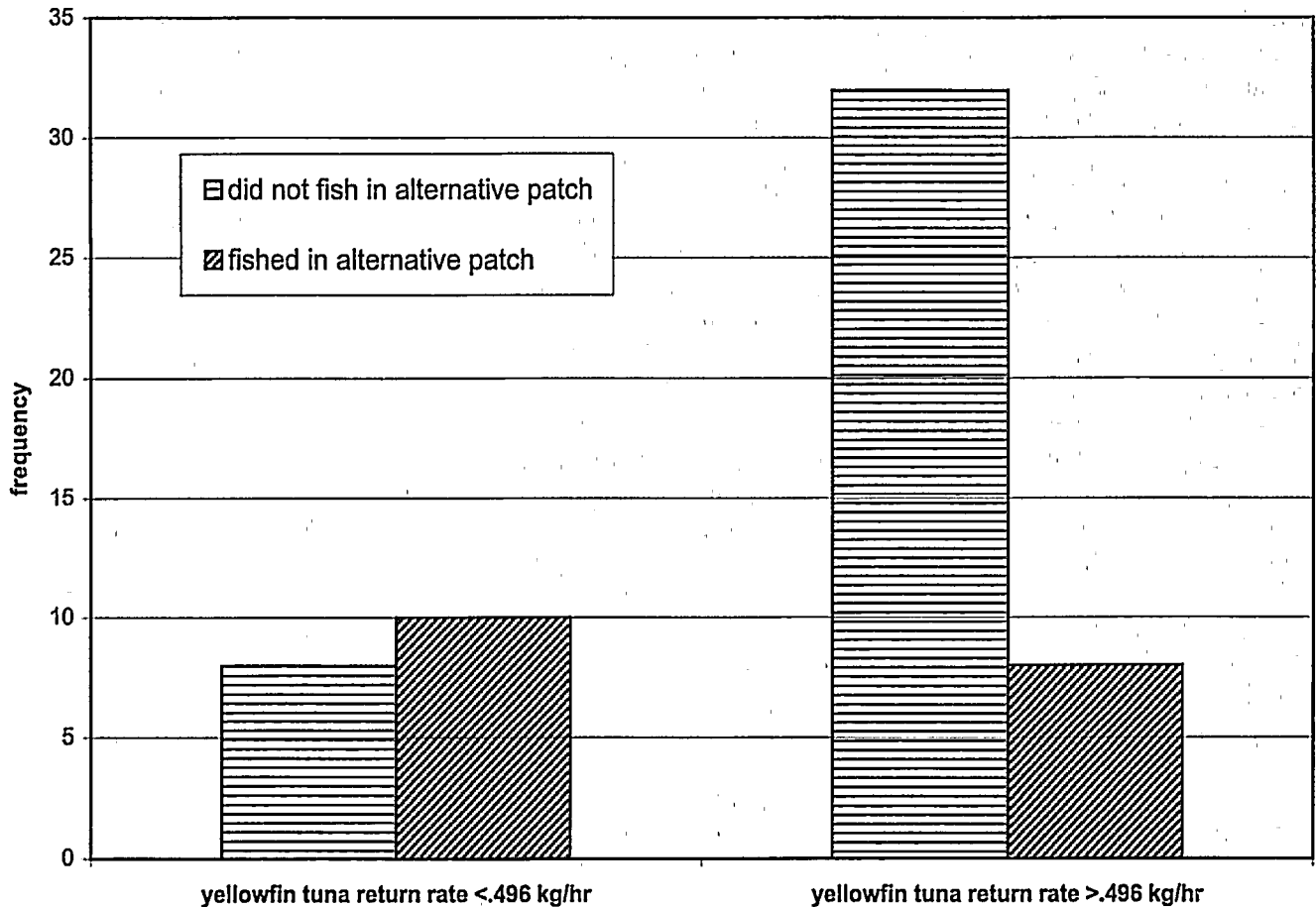
from the highest ranked patch are low or expected to be low. On 35 days the yellowfin tuna patch was either not exploited (which means that fishers experienced below average productivity in the patch on the day before) or produced a return rate less than the threshold value. On 21 of these days (60 percent), men exploited alternative patches. On 40 days the mean per capita return rate for trolling for yellowfin tuna was greater than the threshold value, and on only eight of these days men pursued alternative fishing patches (20 percent). Nonetheless, why did men exploit alternative patches on eight days that the profitability of the yellowfin tuna patch was above the threshold value? A closer look at the data reveals that on these days men captured less fish and spent less time fishing than on other days that the mean per capita return rate was above the threshold value. On these eight days fishers on average caught 42.8 kg and spent 1,603 minutes in the yellowfin tuna patch, whereas on the 32 days that the per capita return rate was above the threshold value and men did not fish in alternative patches, men on average returned with 96.3 kg ( $t = 1.7, p = .017, df = 23$ ) and spent 2473 minutes ( $t = 1.7, p = .011, df = 23$ ) in the yellowfin tuna patch. It is not obvious from the data why men chose shorter foraging times on these days. It is possible that men were forced to return earlier than would be expected on a productive day because of competing demands on their time. If so, however, it is not clear what the demands were. Men often spend the late morning and afternoon cooperatively repairing

canoes or houses (see Sosis 1997), but men only engaged in these activities on three of the eight days. In addition, a review of daily field notes did not reveal anything extraordinary about these days. It seems more likely that fishers perceived something in the fishing conditions (such as changing prey movements or wind strength) that suggested a decline in returns. Indeed, on six of the eight days men exploited the reef fish patch, which was only pursued when winds and tide were calm (suggesting a change in the wind patterns while men were in the yellowfin tuna patch).

In the remainder of this section I will discuss the tests of each prediction, suggest alternative explanations, and discuss directions for future analyses.

#### Prediction 1

As predicted, yellowfin tuna, the most frequently exploited patch by any measure provided the highest mean per capita return rate. The rank order of the mean per capita return rates from exploiting the lagoon-bottom, dogtoothed tuna, and Nine-mile reef patch and their correlation with total fisher hours is less clear. Although the correlation between profitability and patch residence time has been evaluated by others (e.g., Smith 1991), the theoretical basis of the prediction is questionable under a variety of conditions. If the amount of time that foragers can spend pursuing resources is constrained, foragers may be expected to spend more time in a patch of lower profitability. For example, as mentioned



**FIGURE 4.** The frequency that alternative patches were exploited when the yellowfin tuna patch productivity in the morning was greater than or less than 0.496 kg/hr (threshold value).

above, if optimal foraging time is only a few hours, central place foragers may choose to exploit a lower-ranked patch that is closer, has higher initial gains, or lower variance than a patch of higher average profitability (see Hill et al. 1987: 21–22).

Nonetheless, it is curious that men spent any time fishing at Nine-mile reef, especially given its distance from Ifaluk. It is possible that men were simply testing the productivity of this patch. If fishing had been productive there, it would have been interesting to see if fishers regularly returned. However, this “testing the waters” hypothesis is unlikely to explain why men exploit the dogtoothed tuna patch, since men repeatedly torch fished over a two-week period despite consistently low returns. If men were simply gathering information about the profitability of the dogtoothed tuna patch, we would expect fewer men to fish as more information about the low profitability was gathered. However, over the two week period that men exploited this patch, the number of torch fishers ( $r^2 = .27$ ,  $p = .07$ ,  $n = 12$ ) and torch fisher hours ( $r^2 = .39$ ,  $p = .03$ ,  $n = 12$ ) both increased.

It is important to note that when torch fishers and men who fished at Nine-mile reef were asked why they were expending so much time and energy in these activities when they were clearly not providing much fish,<sup>13</sup> men always responded that they had expected to catch more fish. The fishers

had high expectations before exploiting these patches and were genuinely disappointed in their returns. During the weeks of preparation that lead up to the first torch-fishing event of the season, men often described the large amounts of fish they would catch. In the past men may have caught more fish torch fishing, as well as trolling at Nine-mile reef, although empirical data are not available. Burrows and Spiro estimate that 100 pounds of fish were caught (the catch was not weighed) during the only time men fished at Nine-mile reef during their stay, yet they still comment that it was “hardly worth the effort of the long trip” (1957:106). Regardless of their past experiences in each of these patches, Ifaluk men appear to have responded to the poor returns when exploiting the Nine-mile reef by largely avoiding the patch, whereas their willingness not only to continue exploiting the dogtoothed tuna patch, but also increase their exploitation of this patch despite poor returns, suggests that there may be additional factors involved that will require further examination.

One possible explanation of why men exploit the dogtoothed tuna patch is that owing to differences in how fish are distributed (see Sosis 2000a, 2001), men might achieve higher rates of consumption when they torch fish than when they troll for yellowfin tuna or rope fish. Indeed, of fish that are cooperatively acquired on Ifaluk, dogtoothed

tuna are the least widely distributed (Sosis 2001). Here we have assumed that kilograms produced per hour is the appropriate currency to evaluate Ifaluk patch choice decisions. However, Hawkes (1993) has argued that gain rate maximization may not be an appropriate currency for foragers who share their harvest without receiving return benefits, such as sharing via tolerated theft (Blurton Jones 1987). She suggests that consumption rates, especially family consumption rates, may be more important than production or acquisition rates in understanding human foraging decisions. This insight may be critical for evaluating patch choice decisions because foragers may respond to fluctuations in their marginal gains in consumption rather than their marginal gains in production. To evaluate this possibility, I reanalyzed the data presented here using per capita consumption rates rather than production rates (Sosis 2001). Results indicate that although fish caught in other patches are more widely distributed than fish caught in the dogtoothed tuna patch, the consumption rates of torch fishers and their kin are still considerably lower than the consumption rates of men pursuing fish in other patches.

Another possible explanation of why men torch fish is that it is a form of costly signaling (Grafen 1990; Smith and Bliege Bird 2000; Zahavi 1977). In other words, the goal of torch fishing might not be long-term resource intake, but may be better understood as a display by certain males that advertises high quality and skills. A number of factors are consistent with this thesis. The ritual activities and extraordinary preparations of torch fishing are energetically costly, suggesting that the net production rate of torch fishing may (comparatively) be even lower than the results presented here indicate. In addition, the highly public nature of torch fishing events (recall that women and children actually watch the men fish) also suggests that torch fishing might be some sort of display. Initial analyses using torch-fishing data to test several hypotheses derived from costly signaling theory are supportive (Sosis 2000b). Fishing at Nine-mile reef also has some of the ritual and public aspects of torch fishing, and thus costly signaling theory may be useful in explaining why men exploit this patch.

### **Prediction 2**

The mean per capita return rate is higher for solitary fishing than rope fishing, and on nonwindy days men spent more fisher-hours solitary fishing than rope fishing. Several points are worth mentioning. First, the total fisher hours of solitary fishing is slightly underestimated owing to missing data for three events (their inclusion would likely strengthen the result). Second, rope fishing is likely to be energetically more costly than solitary fishing, thus the relative difference between net return rates is probably even greater than indicated in Table 2. Unfortunately, with the current dataset it is not possible to evaluate this. Third, the use of total fisher-hours as a currency to measure travel and residence time in a patch may be a poor choice when comparing solitary and rope fishing since they differ so greatly in number of fishers

per event. Rope fishing is the largest of the cooperative fishing techniques on Ifaluk (32 and 29 men participated in the two observed events) and solitary fishing is obviously the smallest.

Over the full observation period of 114 days, men did not rope fish again, but there were an additional 18 solitary fishing events (15 men engaged in 57 total events). The mean per capita return rate for these events is less than among the subsample of the dataset used in this paper (0.89 kg/hr). Consistent with Prediction 2, the 12 men who solitary fished over the 114-day observation period (for whom there are data) spent more hours solitary fishing than rope fishing on nonwindy days (131.3 vs. 33.0 fisher-hours). Nevertheless, it is not obvious why more men did not solitary fish. Those who did fish solitarily often mentioned how much they enjoyed solitary fishing because it was one of the few opportunities they had to spend some time alone. The most likely reason that more men did not solitary fish is that many men do not have the fishing skills needed to make solitary fishing profitable. Solitary fishing is the most skill-intensive fishing method on Ifaluk. Previously (Sosis 2000a), I argued that men face a trade-off between attending elementary school and acquiring fishing skills. Consequently, the introduction of Western schooling on Ifaluk may have produced a generation of less-skilled fishermen.

The comparison between solitary and rope fishing raises a fundamental issue regarding the costs of cooperation, which are typically ignored in optimal foraging models. Cooperative foraging requires coordinating the labor efforts of multiple individuals. The costs of this coordination may lower the net benefits of some cooperative foraging strategies and, consequently, reduce the frequency that they occur. Rope fishing utilizes the largest labor force of any fishing method on Ifaluk and is thus likely to be the most difficult to organize and coordinate. It should be noted, however, that coordination and mobilization of large numbers of men is quite common in other areas of labor on Ifaluk, such as roof rethatching, canoe repairs, and house building. At least one of these activities occurs about every week on Ifaluk. For each of these activities there is an expectation that all men of the atoll will participate and the compliance rates are very high (Sosis unpublished data). In addition, during the summer atoll-wide cooperative fishing occurs about once every two weeks (see Betzig 1988). Nonetheless, future research on Ifaluk and elsewhere should explore the effects of coordinating the labor effort of multiple foragers on prey and patch choice decisions (see Alvard 2001).

### **Prediction 3**

Men are less likely to troll for yellowfin tuna on days when the mean per capita return rate for trolling on the preceding day was below the overall foraging return rate for all alternative patches. Interestingly, men never avoided the yellowfin tuna patch when the per capita returns on the previous day were above average (i.e., > 1.68 kg/hr). A closer look at the results, however, shows that men occasionally

troll for yellowfin tuna when their return rates on the previous day are low. Indeed, even when the return rates for trolling on the previous day are below the threshold value (0.496 kg/hr), men exploited the yellowfin tuna patch more often than they did not. The chi-square analysis is only significant because men almost always troll when the return rate for trolling on the previous day is *above* the overall foraging return rate. Why do men not avoid the yellowfin tuna patch more frequently when the return rates are low on the previous day? First, men do fish less frequently when the mean per capita return rate for trolling on the previous day is less than the threshold value. The average number of men who trolled when the mean per capita return rate for trolling on the previous day was less than the threshold value was 9.1, and the average number of men who trolled when the mean per capita return rate on the previous day was greater than the threshold value was 13.0. This difference is significant ( $t = 3.1$ ,  $p = .004$ ,  $df = 33$ ), which suggests that men are responding to the outcome of the previous day's fishing event. Second, men undoubtedly also use cues other than the previous day's catch (such as wind and tide strength) to determine the profitability of trolling on a given day.

#### **Prediction 4**

Ifaluk men are more likely to fish in an alternative patch when they do not troll for yellowfin tuna in the morning. In other words, when men expect the profitability of the yellowfin tuna patch to be low, they forgo it in pursuit of alternative patches. Men exploited alternative fishing patches on 11 of 17 days in which men did not troll in the morning. On each of the six days that men did not troll for yellowfin tuna or fish in an alternative patch, severe rain or the arrival of the Microspirit from Yap (which always disrupted normal daily life; see note 3) can explain why men did not fish.

Although Ifaluk men do not discuss fishing in terms of profitabilities, marginal gains, and return rates, they are certainly aware that trolling for yellowfin tuna is the most productive means of harvesting fish during the trade wind season. Their justification for pursuing alternative patches is always, at least partially, a response to poor actual or perceived fishing conditions in the yellowfin tuna patch. Men explained why they did not troll for yellowfin tuna on certain mornings simply and directly: "There are no fish." It is interesting to note that men never claimed that they expected the returns from solitary or rope fishing to be particularly good, they were simply making the best of a bad situation. Although men similarly claimed that the reason they were exploiting the Nine-mile reef or dogtoothed tuna patch was because of the low expected returns from the yellowfin tuna patch, as mentioned above, they also had high expectations about the returns they would achieve in these alternative patches, which of course were never met.

#### **Prediction 5**

Men are much more likely to pursue alternative fishing patches on days when the mean per capita return rate for

trolling in the morning was less than the overall return rate of alternative patches. Indeed, men pursued alternative patches on only eight days when the mean per capita return rate for trolling that morning was greater than the threshold value. However, when the mean per capita return rate for trolling was less than the threshold value, men were only slightly more likely to pursue an alternative patch than not pursue one.

Despite the success of the analyses presented here, we have not explained why men did not pursue alternative patches more frequently on mornings when the yellowfin tuna patch exhibited low productivity. There are several possible explanations. First, poor weather conditions that affect all fishing methods, such as rain, may explain why men did not fish in alternative patches on some of these days, although it is not clear if poor weather can account for every day that men avoided alternative patches when the yellowfin tuna patch was not profitable. Second, just as Ifaluk men respond to variation in the productivity of the yellowfin tuna patch, they undoubtedly also respond to variation in the productivity of alternative patches. It has implicitly been assumed here that fishers estimate the profitability of alternative patches as the seasonal average, yet men surely update their knowledge on the profitability of alternative patches regularly. Thus, fishers may avoid alternative patches even when the yellowfin tuna patch exhibits low profitability, because the expected gains in alternative patches may be even lower. Third, a closer look at Table 3 suggests another possible explanation. Men were more likely to pursue alternative patches toward the end of the observation period than the beginning. The daily mean per capita return rate from trolling does not entirely explain this. Although the daily mean per capita return rate from trolling declines over the observation period, the decline is not significant ( $r = -.14$ ;  $p = .28$ ). It is possible that the risk of not catching any fish while trolling is what really motivates men to pursue alternative patches. Concurrent with the decline in daily mean per capita trolling return rate (albeit not significant) is a reduction in trolling frequency. In the first 38 days of the observation period (December 19, 1994–January 25, 1995) 90 canoes trolled for yellowfin tuna compared with 64 for the remaining 37 days of the observation period (January 26, 1995–March 3, 1995). Twelve percent (11 out of 90) of the canoes that trolled during the first half of the observation period caught no fish, compared to 45 percent (29 out of 64) during the second half of the observation period. This resulted in eight days during the second half of the observation period in which no fish were captured in the yellowfin tuna patch, whereas in the first half of the observation period fish were captured every day that men trolled for yellowfin tuna. Returning to our earlier question of why men did not pursue alternative patches more frequently on mornings when the profitability of the yellowfin tuna patch was low, it may be that men will tolerate poor returns as long as they are catching something, but when they risk catching nothing at all they pursue alternative fishing patches.

**Prediction 6**

Of the 23 events in which Ifaluk men exploited alternative patches on days that men trolled for yellowfin tuna, 16 events resulted in a higher mean per capita return rate than the trolling of that morning. These results however are highly biased by fishing method. Specifically, solitary fishing regularly resulted in a higher mean per capita return rate (ten of 12 events), whereas torch fishing is more ambiguous (five of ten events were higher). Interestingly, in four of the five events that the mean per capita return rate was higher for torch fishing than trolling, no fish were caught during the morning trolling. In other words, as long as men caught something while trolling, their return rate was generally higher than the return rate of the torch fishing event that occurred on the same day. As discussed above, these results may suggest that there is something unique about torch fishing that needs to be further explored.

**CONCLUSION**

Optimal foraging models have been useful in understanding a wide range of foraging behavior, although applications of the patch choice model, including this study, have been limited by a lack of appropriate data. Previous patch choice studies have been unable to explain why foragers spend any time in patches other than the most profitable patch. Here, the availability of a complete and continuous dataset of all fishing activities over a sampled period enabled us to demonstrate that Ifaluk men are responding to daily variation in their fishing returns.

Fishing on Ifaluk is a probabilistic activity with high variance in returns even for the most skilled fishermen. Environmental cues such as wind patterns, strength of tide, foraging behavior of other predators such as birds, as well as the amount of fish caught on the previous day can indicate better or worse fishing conditions. However, a fisherman does not know *a priori* what his actual return rates will be. Nonetheless, the analyses presented here suggest that Ifaluk fishers have an excellent understanding of their foraging environment and that they are responding to daily variations in the profitability of the patches they exploit. One merit of the hypothetico-deductive research tradition employed by behavioral ecologists (Winterhalder and Smith 1992) is that by empirically evaluating hypotheses derived from theoretical expectations, results always suggest future lines of inquiry. All explanatory models are based on assumptions, and failed predictions suggest a reevaluation of those assumptions. Even when results are supportive of the tested hypotheses, assumptions can be modified to improve the explanatory power of the model. Here, the analyses of Ifaluk patch choice decisions largely conform with expectations that men are seeking to maximize their net caloric intake, however, the analyses have also pointed to a fishing method, namely torch fishing, which does not appear to meet this expectation. The analyses presented here also raise other important issues that need to be explored.

Men's foraging goals have been a topic of significant interest among behavioral ecologists (e.g., Bliege Bird et al. 2001; Hawkes 1990, 1993; Hill and Kaplan 1993). The predictions generated and tested here are all based on the assumption that long-term (production) rate maximization is the goal of Ifaluk fishers. Despite significant results, the analyses presented here have not eliminated alternative goals, such as the pursuit of risk minimization, which may also impact fishing decisions. Although various studies have examined how human foragers respond to risk (see Winterhalder et al. 1999), most theoretical and empirical work has concentrated on how food-sharing patterns are a risk reducing mechanism that lowers the high variability in daily hunting returns (e.g., Kaplan et al. 1990). Less attention has been given to how foraging decisions are impacted by the prospect of risk (but see Winterhalder 1986, 1990). Understanding how foragers evaluate the benefits and costs of pursuing patches that exhibit varying degrees of profitability and variance is a critical issue. Under what conditions are foragers expected to forgo patches with high profitability but high variance in daily returns, in favor of pursuing patches with lower profitability and lower variance in daily returns? As Winterhalder (1990) notes, foraging strategies may be aimed at avoiding daily returns that are less than some minimum amount. Although several field studies have evaluated risk minimization models in pastoral (e.g., Mace and Houston 1989) and agricultural (e.g., Hegmon 1989) communities, strong empirical tests have yet to be pursued in foraging populations. Future work will need to explore whether risk minimization is a goal of Ifaluk fishers. The increased pursuit of alternative patches over the observation period, which coincides with the increased rate of days in which no fish were caught in the yellowfin tuna patch, suggests that risk might be an important factor in Ifaluk patch choice decisions.

The results presented here also suggest at least three areas where anthropologists should focus their effort when collecting data on patch choice decisions. First, datasets that capture all the patch choice decisions for a group of foragers over a sample period will be critical. Without a complete and continuous record of foraging choices, it is difficult to evaluate foragers' responses to rapidly changing patch profitabilities. Unlike Ifaluk fishers, in many populations different individuals or groups of foragers simultaneously pursue different patches. Under these conditions, it will be challenging, but important, to explain this variance in patch choice decisions. Second, as others have noted (e.g., Kaplan and Hill 1992; Winterhalder 1981), measuring the gain curve within patches will be essential for testing hypotheses derived from the MVT and improving our understanding of human foraging decisions. To accomplish this, naturalistic observations, such as scan sampling and focal follows, will likely need to be complemented with experimental techniques. Third, most foraging studies have concentrated on the benefits of alternative foraging decisions, while much less attention has been given to measuring and evaluating foraging costs. The energetic costs of pursuit undoubtedly impact prey and patch choice decisions; however, most research on foraging decisions

(this one included) has either ignored, or employed very rough estimates, of forager energetic expenditure. To fully understand the ecological factors that impact foraging decisions, future work must seek to improve our measurements of the caloric costs that foragers experience while pursuing resources. Other costs, such as producing and maintaining foraging technology and the costs of coordinating labor effort among foragers, should also be explored.

Behavioral ecologists use optimization theory and derived models as a tool to systematically improve our understanding of human behavioral decisions. Over the past 20 years, behavioral ecologists have established an impressive literature that has significantly enhanced our knowledge about how human foragers acquire resources (see Winterhalder and Smith 2000). As each new study improves our understanding of the processes and constraints that impact foraging decisions, new questions are additionally raised. These questions lead us into new avenues of inquiry and point to an exciting and promising future of foraging studies in behavioral ecology.

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#### NOTES

*Acknowledgments.* I wish to thank Doug Bird, Rebecca Bird, Mike Gurven, Penn Handwerker, Kim Hill, and four anonymous reviewers for reading this manuscript and providing very useful suggestions. I also thank Robert Walker for providing a helpful mathematical model of patch choice decisions that clarified my understanding of several important issues. Special thanks to Kim Hill for his detailed comments on patch choice models and for correcting some significant errors in an earlier draft of this manuscript. The remaining errors are all my own. The National Science Foundation (SBR9423070), L. S. B. Leakey Foundation, UNM Office of Graduate Studies, and UNM Department of Anthropology generously supported this project.

1. For a more detailed overview of patch choice models than will be presented here, see Stephens and Krebs (1986) and Krebs and Kacelnik (1991).
2. For example, consider central place foragers who on certain days can only forage two hours and on others can forage eight hours. When available foraging time is short, foragers may choose to exploit lower quality patches if the travel time to more productive patches is too high, or if high-quality patches initially have slowly increasing marginal gains. Thus, without knowledge of available foraging time, it is difficult to make any predictions about patch choice decisions.
3. Store supplies are purchased from the Microspirit, a government-owned ship that travels to Ifaluk and the other outer islands of Yap State about once every two months.
4. Employment on Ifaluk is limited to 19 jobs (e.g., teachers, medical dispensators, school chef), which are paid for by the FSM government. On Falalop atoll, where this study was conducted, only three individuals (all men) were employed.
5. Previous publications referred to this fishing method as "cooperative sail-fishing" (Sosis et al. 1998, 2000a). In this article I will refer to this fishing method as morning trolling or trolling for yellowfin tuna, and not as "cooperative sail-fishing," since three fishing methods that will be discussed here are cooperative and utilize sailing canoes.

6. Men also spend time in the afternoon preparing their fishing lines, hooks, and canoes for the following morning (see Sosis 1997).

7. Nine-mile reef was known as *Fes* in Woleaian, the primary language spoken on Ifaluk (cf. Burrows and Spiro 1957).

8. See Burrows and Spiro (1957) for an excellent description of the role of the magician in Ifaluk society.

9. These data refer to daytime solitary fishing. I did not collect systematic data on nighttime solitary fishing activities. However, casual discussions about solitary fishing indicate that (1) nighttime solitary fishing occurred less frequently than daytime solitary fishing, and (2) no individual exclusively fished at night.

10. Data on the energetic expenditure of fishing and labor activities on Ifaluk were collected using the Energy Expenditure Prediction Program (see Sosis 1997).

11. These five species were chosen among the 62 species of reef fish caught because of the availability of caloric information.

12. The MVT predicts that foragers will respond to variations in the marginal productivity of a patch, but the critical issue is determining the time frame over which marginal gains are relevant (Hill et al. 1987). Theoretically, the MVT suggests that foragers should be responding to instantaneous marginal gains (i.e., the derivative of the gains curve). However, it is unlikely that selection would have produced response mechanisms that would be so sensitive to variations in the foraging acquisition rate since such small deviations in resource acquisition rate are not likely to have significant fitness effects for most organisms. Should we expect human foragers to be maximizing their marginal gains per second, minute, hour, day, or week? The answer to this question lies in the response patterns, and mechanisms used to produce those patterns, that we expect selection to have favored. In other words, we expect foragers to respond to fluctuations in their marginal gains that will have a meaningful impact on their fitness. For this article, the issue is academic owing to the constraints of the dataset. Here, the time frame I will consider are fluctuations in gains per day. Because men do not spend the same amount of time foraging each day, they should not only be responsive to fluctuations in their daily gains, but, more importantly, they should be responsive to changes in their return rate each day. Although foragers are likely to be responding to changes in their return rate over a shorter time scale, daily changes in consumption are assumed to have significant health and fitness effects.

13. Both of these patches were also exploited after the observation period reported here, with a similar lack of success.

#### REFERENCES CITED

- Alvard, M.  
2001 Mutualistic Hunting. *In* The Early Human Diet: The Role of Meat. C. Stanford and H. Bunn, eds. Pp. 261–278. New York: Oxford University Press.
- Bailey, R.  
1990 The Behavioral Ecology of Efe Pygmy Men in the Ituri Forest. Ann Arbor: University of Michigan Press.
- Beckerman, S.  
1983 Carpe Diem: An Optimal Foraging Approach to Bari Fishing and Hunting. *In* Adaptive Responses of Native Amazonians. R. Hames and W. Vickers, eds. Pp. 269–299. New York: Academic Press.
- Betzig, L.  
1988 Redistribution: Equity or Exploitation? *In* Human Reproductive Behavior: A Darwinian Perspective. L. Betzig, M. Borgerhoff Mulder, and P. Turke, eds. Pp. 49–63. Cambridge: Cambridge University Press.
- Bird, D.  
1998 Behavioral Ecology and the Archaeological Consequences of Central Place Foraging among the Meriam. *In* Rediscovering Darwin: Evolutionary Theory and Archaeological Explanation, vol. 7. C. Barton and G. Clark, eds. Pp. 291–306. Washington, DC: Archaeological Papers of the American Anthropological Association.

- Bliege Bird, R., E. Smith, and D. Bird  
2001 The Hunting Handicap: Costly Signaling in Human Male Foraging Strategies. *Behavioral Ecology and Sociobiology* 50:9-19.
- Blurton Jones, N.  
1987 Tolerated Theft, Suggestions about the Ecology and Evolution of Sharing, Hoarding and Scrounging. *Social Science Information* 26:31-54.
- Burrows, E., and M. Spiro  
1957 *An Atoll Culture: Ethnography of Ifaluk in the Central Carolines*. Westport, CT: Greenwood Press.
- Charnov, E.  
1976 Optimal Foraging Theory: The Marginal Value Theorem. *Theoretical Population Biology* 9:129-136.
- Charnov, E., and G. Orians  
1973 Optimal Foraging: Some Theoretical Explorations. Mimeo-graph, Department of Biology, University of Utah.
- Charnov, E., G. Orians, and K. Hyatt  
1976 The Ecological Implications of Resource Depression. *American Naturalist* 110:247-259.
- Freeman, O., ed.  
1951 *Geography of the Pacific*. New York: John Wiley and Sons.
- Grafen, A.  
1990 Biological Signals as Handicaps. *Journal of Theoretical Biology* 144:517-546.
- Hames, R.  
1980 Games Depletion and Hunting Zone Rotation among the Ye'kwana and Yanomamo of Amazonas, Venezuela. In *Working Papers on South American Indians*. R. Hames, ed. Pp. 24-62. Bennington, VT: Bennington College.
- Hames, R., and W. Vickers  
1982 Optimal Foraging Theory as a Model to Explain Variability in Amazonian Hunting. *American Ethnologist* 9:358-378.
- Hawkes, K.  
1990 Why Do Men Hunt? Benefits for Risky Choices. In *Risk and Uncertainty in Tribal and Peasant Economies*. E. Cashdan, ed. Pp. 145-166. Boulder: Westview Press.  
1993 Why Hunter-Gatherers Work: An Ancient Version of the Problem of Public Goods. *Current Anthropology* 34:341-361.
- Hawkes, K., K. Hill, and J. O'Connell  
1982 Why Hunters Gather: Optimal Foraging and the Ache of Eastern Paraguay. *American Ethnologist* 9:379-398.
- Hawkes, K., J. O'Connell, and N. Blurton Jones  
1991 Hunting Income Patterns among The Hadza: Big Game, Common Goods, Foraging Goals, and the Evolution of the Human Diet. *Philosophical Transactions of the Royal Society* 334:243-251.
- Hegmon, M.  
1989 Risk Reduction and Variation in Agricultural Economies: A Computer Simulation of Hopi Agriculture. *Research in Economic Anthropology* 11:89-121.
- Hill, K., and K. Hawkes  
1983 Neotropical Hunting among the Ache of Eastern Paraguay. In *Adaptive Responses of Native Amazonians*. R. Hames and W. Vickers, eds. Pp. 223-267. New York: Academic Press.
- Hill, K., and H. Kaplan  
1993 On Why Male Foragers Hunt and Share Food. *Current Anthropology* 34:701-706.
- Hill, K., H. Kaplan, and A. Hurtado  
1987 Foraging Decisions among Ache Hunter-Gatherers: New Data and Implications for Optimal Foraging Models. *Ethology and Sociobiology* 8:1-36.
- Kaplan, H., and K. Hill  
1992 The Evolutionary Ecology of Food Acquisition. In *Evolutionary Ecology and Human Behavior*. E. Smith and B. Winterhalder, eds. Pp. 167-201. New York: Aldine de Gruyter.
- Kaplan, H., K. Hill, and A. M. Hurtado  
1990 Risk, Foraging, and Food Sharing among the Ache. In *Risk and Uncertainty in Tribal and Peasant Economies*. E. Cashdan, ed. Pp. 107-143. Boulder: Westview Press.
- Kelly, R.  
1995 *The Foraging Spectrum*. Washington, DC: Smithsonian Institution Press.
- Krebs, J., and A. Kacelnik  
1991 Decision-Making. In *Behavioural Ecology*. 3rd edition. J. Krebs and N. Davies, eds. Pp. 105-136. Oxford: Blackwell Scientific Publications.
- MacArthur, R., and E. Pianka  
1966 On Optimal Use of a Patchy Environment. *American Naturalist* 100:603-609.
- Mace, R., and A. Houston  
1989 Pastoralist Strategies for Survival in Unpredictable Environments: A Model of Herd Composition That Maximizes Household Viability. *Agricultural Systems* 31:185-204.
- O'Connell, J., and K. Hawkes  
1981 Alyawara Plant Use and Optimal Foraging Theory. In *Hunter-Gatherer Foraging Societies*. B. Winterhalder and E. Smith, eds. Pp. 99-125. Chicago: Chicago University Press.  
1984 Food Choice and Foraging Sites among the Alyawara. *Journal of Anthropological Research* 40:504-535.
- Smith, E.  
1981 The Application of Optimal Foraging Theory to the Analysis of Hunter-Gatherer Group Size. In *Hunter-Gatherer Foraging Societies*. B. Winterhalder and E. Smith, eds. Pp. 36-65. Chicago: Chicago University Press.  
1983 Anthropological Applications of Optimal Foraging Theory: A Critical Review. *Current Anthropology* 24: 625-651.  
1987 Optimization Theory in Anthropology: Applications and Critiques. In *The Latest on the Best: Essays on Evolution and Optimality*. J. Dupre, ed. Pp. 201-249. Cambridge, MA: Bradford Books/MIT Press.  
1991 Inujjuamiut Foraging Strategies. New York: Aldine.
- Smith, E., and R. Bliege Bird  
2000 Turtle Hunting and Tombstone Opening: Public Generosity as Costly Signaling. *Evolution and Human Behavior* 21:245-261.
- Sosis, R.  
1997 The Collective Action Problem of Male Cooperative Labor on Ifaluk Atoll. Ph.D. dissertation, University of New Mexico.  
2000a The Emergence and Stability of Cooperative Fishing on Ifaluk Atoll. In *Human Behavior and Adaptation: An Anthropological Perspective*. L. Cronk, N. Chagnon, and B. Irons, eds. Pp. 237-272. New York: Aldine de Gruyter.  
2000b Costly Signaling and Torch Fishing on Ifaluk Atoll. *Evolution and Human Behavior* 21:223-244.  
2001 Sharing, Consumption, and Patch Choice on Ifaluk Atoll: Evaluating an Explanatory Hypothesis of Why Ifaluk Men Torch Fish. *Human Nature* 12:221-245.
- Sosis, R., S. Feldstein, and K. Hill  
1998 Bargaining Theory and Cooperative Fishing Participation on Ifaluk Atoll. *Human Nature* 9:163-203.
- Stephens, D., and J. Krebs  
1986 *Foraging Theory*. Princeton: Princeton University Press.
- Tracey, J., D. Abbott, and T. Arnow  
1961 *Natural History of Ifaluk Atoll*. Honolulu: University of Hawaii Press.
- Winterhalder, B.  
1981 Foraging Strategies in the Boreal Forest: An Analysis of Cree Hunting and Gathering. In *Hunter-Gatherer Foraging Societies*. B. Winterhalder and E. Smith, eds. Pp. 66-98. Chicago: Chicago University Press.  
1986 Optimal Foraging: Simulation Studies of Diet Choice in a Stochastic Environment. *Journal of Ethnobiology* 6:205-223.  
1990 Open Field, Common Pot: Harvest Variability and Risk Avoidance in Agricultural and Foraging Societies. In *Risk and Uncertainty in Tribal and Peasant Economies*. E. Cashdan, ed. Pp. 67-87. Boulder: Westview Press.
- Winterhalder, B., F. Lu, and B. Tucker  
1999 Risk-Sensitive Adaptive Tactics: Models and Evidence from Subsistence Studies in Biology and Anthropology. *Journal of Archaeological Research* 7:301-348.
- Winterhalder, B., and E. Smith  
1992 Evolutionary Ecology and the Social Sciences. In *Evolutionary Ecology and Human Behavior*. E. A. Smith and B. Winterhalder, eds. Pp. 3-23. New York: Aldine de Gruyter.  
2000 Analyzing Adaptive Strategies: Human Behavioral Ecology at Twenty-Five. *Evolutionary Anthropology* 9:51-72.
- Zahavi, A.  
1977 The Cost of Honesty (Further Remarks on the Handicap Principle). *Journal of Theoretical Biology* 67:603-605.



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TITLE: Patch Choice Decisions among Ifaluk Fishers  
SOURCE: American Anthropologist 104 no2 Je 2002  
WN: 0215204705015

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